Suitability of Commercially Available Insect Traps and Pheromones for Monitoring Dusky Sap Beetles (Coleoptera: Nitidulidae) and Related Insects in Bt Sweet Corn

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ABSTRACT Two trap types and pheromone sources for the dusky sap beetle, *Carpophilus lugubris* Murray (Coleoptera: Nitidulidae), were compared in *Bacillus thuringiensis* (Bt) and non-Bt sweet corn fields over a 3-yr period. Overall, commercial traps and pheromones were equally effective as experimental traps and pheromones used previously for capturing *C. lugubris* and other sap beetle species. The commercial trap often caught significantly more *Glischrochilus quadrisignatus* Say than the experimental trap that had been used in previous studies. Bt corn significantly reduced caterpillar damage to ears compared with the non-Bt isoline and did not adversely affect levels of *Orius* sp., the most common insect predator. Sap beetle damage was the most common insect damage to Bt sweet corn ears. Sap beetles were detected by traps at population levels below that which are likely to cause economic concern, indicating commercially available traps and pheromone lures for monitoring sap beetles should be suitable for detecting them under commercial growing conditions.

KEY WORDS *Carpophilus lugubris*, *Helicoverpa zea*, *Ostrinia nubilalis*, insect predators

INSECT DAMAGE CAUSES MAJOR economic losses to sweet corn (Flood and Hutchinson 1995). The introduction of a gene coding for the crystal protein of *Bacillus thuringiensis* Berliner (Bt) into maize, *Zea mays* L., has greatly reduced the damage caused by both the European corn borer, *Ostrinia nubilalis* (Hübner), and corn earworm, *Helicoverpa zea* (Boddie), such that the number of insecticide treatments needed to control these insect pests can be greatly reduced or eliminated (Dively et al. 1998; Lynch et al. 1999a, 1999b; Dowd 2000; Burkness et al. 2001; Musser and Shelton 2003). However, sap beetles, especially the dusky sap beetle, *Carpophilus lugubris* Murray, are capable of causing significant damage in Bt sweet corn when insecticides are not used (Dively et al. 1998, Dowd 2000). This damage is apparently occurring because sap beetles were formerly controlled by insecticides used to control caterpillar pests (Dowd 2000). Damage is caused not only by adults but also by larvae that can penetrate far down from ear tip, such that ear tip trimming is not sufficient to eliminate undesirable damage (Connell 1956, Dively et al. 1998). Thus, insecticides or other management strategies may be necessary when sap beetle populations in Bt corn reach levels of economic concern.

Previous studies have identified pheromones (Bartelt 1999), coattractants (Dowd and Bartelt 1991, Lin and Phelan 1991), and traps (Dowd et al. 1992, Williams et al. 1993, James et al. 1996) of potential use for monitoring populations of *C. lugubris.* Examples of these tools were combined and tested in sweet corn for monitoring *C. lugubris* and others species in Illinois (Dowd 2000). It was shown that trap-based monitoring of *C. lugubris* and its relatives is likely to be valuable in determining when populations of these insects are sufficiently high to initiate pest management strategies (Dowd 2000). However, neither the traps nor the pheromone used in this previous study were commercially available. We now report that commercially available traps and pheromones can be as effective as the experimental traps used in the previous study for monitoring *C. lugubris* and other species that may be of concern for sweet corn or other commodities. The commercial traps apparently have not been tested on sap beetles previously. The pheromone of *C. lugubris* is comprised of two components in specific ratios that are complicated to synthesize (Bartelt 1999), so verification of efficacy of a new commercial source of material was of interest as well.

Materials and Methods

Field Site and Plot Design. The field site was an ≈0.4-ha area located near Havana, IL (Dowd 2000). It had been planted with corn the year before the ini-

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Fig. 1. (A) USDA Tee trap. (B) Fly-in-Saucer (fly) trap.

tiation of the study. Plot design was similar to that described previously (Dowd 2000) and consisted of three to four alternating eight-row strips ≈80 m in length of Bt and non-Bt sweet corn. Tillage, planting, and weed control were conducted according to conventional agricultural practices for the area (Dowd 2000). Rogers hybrid 'Bonus' in Bt and non-Bt version (Syngenta Seeds, Boise, ID) was planted in the alternating eight row strips.

Traps and Attractants. "Tee" type traps were the same as those used in a previous study and were primarily made of polyvinyl chloride pipe and a clear plastic "jar" (Dowd 2000) (Fig. 1A). Victor "Fly-in Saucer" traps (referred to hereafter as fly traps) (Fig. 1B) were obtained from Great Lakes IPM, Inc. (Vestaberg, MI). These traps are 22 cm in height by 10 cm in width with 1-cm openings into the collection bottle. The clear plastic collection bottle is of ≈1-liter capacity with an opening 6.5 cm in diameter. Traps were priced at $3.00 individually or 12 for $33.60 in 2004. The fly trap was functionally similar to the Tee trap in appearance, and preliminary studies in the spring of 2001 indicated it would trap sap beetles at a comparable rate to the Tee trap. All traps were reused from year to year.

Pheromones for *C. lugubris* were obtained from R. J. Bartelt (USDA–ARS–NCAUR, Peoria, IL). The USDA version of the pheromone consists of 90% by weight of (2*E*,4*E*,6*E*,8*E*)-3,5-dimethyl-7-ethyl-2,4,6,8-undecatetraene (71% purity) and 10% by weight (2*E*,4*E*,6*E*,8*E*)-3,5,7-trimethyl-2,4,6,8-undecatetraene (83% purity) (Bartelt 1999). Impurities are primarily Z-isomers, which do not interfere with trap catch (Bartelt 1999). USDA pheromone septa are formulated by adding 500 μg of blend (typically in 10 μl of hexane) to a red 6-mm-diameter rubber septa (Aldrich, Milwaukee, WI), filling the septa near the top with methylene chloride, and then allowing the solution to soak into the septa while septa are under a beaker in a fume hood (Bartelt 1999). Stock pheromone solutions and prepared septa are stored in the freezer at −20°C until use. The release rate of septa is dependent on temperature and air flow, but at 27°C and 100 ml/min air flow, mean release rates over a 2-wk period are 138 ng/h for the major component and 23 ng/h for the minor component (Bartelt et al. 2004). Although breakdown rates have not been quantitated, activity is typically acceptable for at least 2 wk in the field (Bartelt 1999, Dowd 2000, Bartelt et al. 2004). Pheromones of *C. lugubris* were obtained commercially from Great Lakes IPM, Inc. They are formulated identically to the USDA pheromones except that rubber septa were from West Co. (Lionsville, PA), and BHT was added (J. Hansel, Great Lakes IPM, Inc., personal communication). The pheromones are packaged in sealed envelopes and are reported to last for 2–3 wk (Great Lakes IPM 2004). Pheromones of *C. lugubris* do not affect behavior of sap beetle species in other genera, although coattractants used with the pheromone can attract some species of *Glischrochilus* and *Stelidota* (Williams et al. 1993, Dowd 2000). A fermenting apple juice gel aggregate was used as coattractant with the pheromone and was prepared as described previously (Dowd 2000).

Trap Placement and Ear Sampling. Traps were hung from bent conduit approximately at ear height as described previously (Dowd 2000). Traps were placed throughout the field each year at least 15 m apart, allowing at least two border rows between corn types (Bt and non-Bt). Due to irregular sweet corn growth

Table 1. Comparison of sap beetles captured in different trap types in 2001–2003

Yr	Mean + SE beetles trapped					
	C. lugubris		*G. quadrisignatus*		*S. geminata*	
	Tee	Fly	Tee	Fly	Tee	Fly
2001						
12 July	3.0 ± 0.8a	7.1 ± 1.4b	0.0 ± 0.0	0.7 ± 0.3	0.0 ± 0.0	0.7 ± 0.3
16 July	12.8 ± 1.7a	7.7 ± 2.0a	0.2 ± 0.2a	4.0 ± 0.9b	1.3 ± 0.6a	4.6 ± 1.1b
19 July	1.1 ± 0.4a	2.0 ± 1.5a	0.6 ± 0.2a	3.2 ± 1.2b	1.6 ± 0.6a	2.0 ± 0.8a
23 July	0.3 ± 0.2a	0.8 ± 0.2a	0.1 ± 0.1a	1.3 ± 0.3b	0.8 ± 0.4a	0.2 ± 0.2a
2002						
29 July	0.8 ± 0.5a	0.2 ± 0.2a	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.3	0.0 ± 0.0
1 August	0.5 ± 0.2a	0.5 ± 0.2a	0.7 ± 0.3a	0.2 ± 0.2a	3.8 ± 1.0a	5.2 ± 1.7a
5 August	1.0 ± 0.4a	0.8 ± 0.5a	0.0 ± 0.0	0.2 ± 0.2	3.0 ± 1.5a	1.0 ± 0.4a
7 August	0.2 ± 0.2a	0.7 ± 0.3a	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.3	0.0 ± 0.0
2003						
17 July	2.4 ± 0.7a	2.4 ± 0.5a	0.1 ± 0.1a	1.0 ± 0.6b	4.2 ± 3.1a	3.3 ± 0.8a
21 July	2.2 ± 0.4a	1.9 ± 0.6a	0.2 ± 0.2a	0.6 ± 0.3a	1.5 ± 0.7a	2.2 ± 0.8a
23 July	0.8 ± 0.3a	1.2 ± 0.3a	0.0 ± 0.0	0.1 ± 0.1	1.4 ± 0.5a	0.7 ± 0.4a
28 July	1.0 ± 0.2a	1.2 ± 0.4a	0.4 ± 0.2a	1.0 ± 0.4a	0.7 ± 0.4a	1.0 ± 0.6a
31 July	0.4 ± 0.4a	0.4 ± 0.3a	0.1 ± 0.1a	0.3 ± 0.3a	0.4 ± 0.5a	0.5 ± 0.6a

Total of nine traps of each type used in 2001, six of each type in 2002, and 12 of each type in 2003. Means of values in columns of like dates in rows followed by different letters are significantly different at $P < 0.05$ by analysis of variance. Pairs without letter designations contain a value with a zero variance.

in 2001 and 2002, traps were placed in equivalently aged patches in the field. Nine of the USDA traps and nine of the commercial traps were compared in 2001 (pheromone was not commercially available in 2001). In 2002, 12 traps were place in the field, with three replicates of all possible trap–pheromone combinations. In 2003, 24 traps were placed in the field, with six replicates of all possible trap/pheromone combinations. In 2003, one trap was placed in each row of the center four rows of each strip, and each trap was placed 15 m down the row from the preceding trap. A different trap–pheromone combination was used in each adjacent row. Traps were placed in the field immediately before or no later than 5–10% silking. In all 3 yr, traps were inspected twice weekly over ≈2 wk. Sap beetles were removed, separated according to species, and counted during each trap inspection.

Approximately 21 d after full silking, up to five milk stage ears were removed from the center of each strip at 10-m intervals, except where traps were placed (six to seven samples per strip). All insects present on the ears were counted and identified, and the incidence and numbers of kernels damaged by different insects were determined (Dowd 2000).

Statistical Analysis. Differences in numbers of beetles per trap–pheromone combination were determined by analysis of variance (ANOVA) by using SAS PROC GLM (SAS Institute 2002). Simple one-way ANOVA was used in 2001 because all traps contained USDA pheromone. Factorial analysis was used in 2002 and 2003 due to the presence of different trap/pheromone combinations. Separate analyses were performed for each sample date to compare efficacy of the different traps and pheromones over time. Differences in percentage insect presence on ears were determined with χ^2 analysis by using PROC FREQ (SAS Institute 2002).

Results

Trap Captures. Numbers of all sap beetle species captured in traps were typically highest at or near the beginning of trapping and then declined (Table 1). The most common species varied in different years, but either *C. lugubris*, *Glischrochilus quadrisignatus* (Say), or *Stelidota geminata* (Say) were the most common overall. *Carpophilus antiquus* Melsheimer, *Carpophilus hemipterus* Say, and *Carpophilus brachypterus* Say also were captured. No significant interactions occurred between trap and pheromone types in 2002 or 2003 for either *C. lugubris* or *S. geminata*, and only one significant interaction occurred for *G. quadrisignatus* on one sample date in 2003, so trap captures related to trap type and pheromone type are presented separately in the tables. There was only one occasion over the 3-yr period (12 July 2001) where significantly higher numbers of *C. lugubris* were captured by one trap (fly) versus another (Tee) ($F = 6.58$; df = 1, 17; $P = 0.020$). There was one occasion where the fly trap captured significantly higher numbers of *S. geminata* compared with the Tee trap (16 July 2001) ($F = 7.17$; df = 1, 17; $P = 0.016$). The fly trap caught significantly more *G. quadrisignatus* in three of four instances in 2001 (16 July, 19 July, and 23 July) ($F = 18.50$; df = 1, 17; $P = 0.0005$; $F = 4.66$; df = 1, 17; $P = 0.046$; and $F = 12.10$; df = 1, 17; $P = 0.003$) and one instance in 2003 (17 July) ($F = 4.84$; df = 1, 23; $P = 0.040$), but the same trend was noted in several other occasions. There was only one sample (*G. quadrisignatus* on 21 July 2003) where there was a significant difference ($F = 8.42$; df = 1, 23; $P = 0.009$) in capture of individual sap beetle species or total sap beetle species by the two different pheromone types (pheromone types were not tested in 2001) (Table 2). There was only one sample (*G. quadrisignatus* on 31 July 2003) where there was a significant ($F = 5.00$; df = 1, 23; $P = 0.037$) interaction between trap and pheromone type.

Table 2. Comparison of sap beetles captured by different pheromone sources in 2002–2003

Yr	Mean + SE beetles trapped					
	C. lugubris		*G. quadrisignatus*		*S. geminata*	
	USDA	GLIPM	USDA	GLIPM	USDA	GLIPM
2002						
29 July	1.0 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2a	0.5 ± 0.3a
1 Aug.	0.7 ± 0.2a	0.3 ± 0.2a	0.3 ± 0.2a	0.5 ± 0.3a	3.8 ± 1.2a	5.2 ± 1.6a
5 Aug.	1.2 ± 0.5a	0.7 ± 0.2a	0.2 ± 0.2	0.0 ± 0.0	3.0 ± 1.5a	1.0 ± 0.4a
7 Aug.	0.3 ± 0.2a	0.5 ± 0.3a	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.3
2003						
17 July	2.4 ± 0.7a	2.4 ± 0.5a	0.5 ± 0.5a	0.6 ± 0.4a	5.5 ± 3.0a	2.1 ± 0.6a
21 July	2.2 ± 0.4a	1.9 ± 0.6a	0.8 ± 0.3a	0.1 ± 0.1b	1.3 ± 0.8a	2.3 ± 0.7a
23 July	0.8 ± 0.3a	1.2 ± 0.3a	0.1 ± 0.1	0.0 ± 0.0	1.0 ± 0.4a	1.1 ± 0.6a
28 July	1.0 ± 0.2a	1.2 ± 0.4a	0.8 ± 0.4a	0.7 ± 0.3a	0.8 ± 0.6a	0.8 ± 0.4a
31 July	0.4 ± 0.4a	0.4 ± 0.3a	0.1 ± 0.1a	0.3 ± 0.3a	0.8 ± 0.7a	0.2 ± 0.2a

Total of six traps of each type used in 2002, and 12 of each type in 2003. Means of values in columns of like dates in rows followed by different letters are significantly different at $P < 0.05$ by analysis of variance. Pairs without letter designations contain a value with a zero variance.

Corn Ear Samples. Milk stage sweet corn samples indicated *O. nubilalis* and *H. zea* occurred on <5% of the Bt ears in all 3 yr (Table 3). Total caterpillar incidence on the non-Bt versions of the hybrids ranged from 13.3 to 76.4% over the 3-yr study. Incidence of damage by *H. zea* was significantly lower in Bt compared with non-Bt corn in 2002 ($\chi^2 = 20.61, P < 0.0001$). Incidence of damage by *O. nubilalis* was significantly lower in Bt compared with non-Bt corn in all 3 yr (2001: $\chi^2 = 35.06, P < 0.0001$; 2002: $\chi^2 = 62.22, P < 0.0001$; and 2003: $\chi^2 = 10.93, P = 0.009$). Sap beetle damage incidence was significantly greater in non-Bt than Bt hybrids in 2001 ($\chi^2 = 4.54, P = 0.033$) and 2003 ($\chi^2 = 4.39$; $P = 0.036$). Sap beetle damage was the major type of damage to Bt corn ears in all 3 yr, although in 2002 there were no ears that had more than five kernels damaged by sap beetles. The incidence of *Orius* sp. was ≈10–15% higher overall for Bt compared with non-Bt ears in all 3 yr, but only in 2001 was this difference significant ($\chi^2 = 6.92, P = 0.009$). It was rare for more than one individual *Orius* to be found on an individual ear. Other predators were much less common and are not reported.

Discussion

Even though a variety of sap beetle species cause problems on sweet corn, *C. lugubris* is the most common sap beetle pest of sweet corn ears in the central and northeastern United States (Connell 1956, Sanford and Luckman 1963, Dively et al. 1998, Dowd 2000). Although numbers varied from year to year, *C. lugubris* was one of the more common species caught in the traps in the current study. However, mean numbers of *C. lugubris* and total sap beetles both in traps and ears were considerably lower in 2002 and 2003 than in previous studies in this area (Dowd 2000). Nevertheless, traps of both types, baited with both pheromone types, were still sensitive enough to detect beetles above levels where minimal damage to ears occurred. This information indicates that the trap–attractant combinations seem to have sufficient sensitivity to detect sap beetles at levels below an economic threshold. This ability was most evident in 2002, where sap beetle damage only occurred at a rate of less than five kernels per ear for all ears where sap beetle damage was encountered. Lower numbers detected in traps compared with the previous study (Dowd 2000) may be due to later planting relative to other sweet corn planted at the site when sweet corn was planted on approximately the same date. Several studies have indicated sap beetles tend to predominate in the first fields to silk in any particular area (Connell 1956, Sanford and Luckman 1963). Lower numbers detected in ears compared with previous studies may be due to lower populations in the field. In addition, a higher percentage of tight husks around the tips of the ears was noted for the 'Bonus' hybrid used in the current study (especially in 2002 when only 0.5% of all ears had exposed tips) compared with the previous study (Dowd 2000) when the 'Heritage' was used.

Table 3. Incidence of insects on Bt and non-Bt sweet corn ears 2001–2003

Insect	% incidence					
	2001		2002		2003	
	nonBt	Bt	nonBt	Bt	nonBt	Bt
H. zea	5.6a	1.4a	26.9a	3.2b	2.2a	1.1a
O. nubilalis	22.2a	0.0b	49.5a	0.0b	11.1a	0.0b
Sap beetle	44.4a	32.1b	5.4a	13.8a	22.2a	11.1b
Orius sp.	31.2a	46.4b	33.3a	46.8a	30.0a	40.9a
Ear no.	144	140	93	94	90	93

Values in rows for like years followed by different letters are significantly different by χ^2 analysis at $P < 0.05$.

As reported previously (Dowd 2000), multiple sap beetle species were captured in the traps. In the current study, *C. lugubris* was the most commonly collected sap beetle in traps in 2001, whereas *S. geminata* was most common in 2002 and 2003. In previous studies, *C. lugubris* was most common in 1998, and *S. geminata* in 1999 (Dowd 2000). This again may be due to earlier planting of other sweet corn in the area in 2002 and 2003, which drew *C. lugubris* to the earlier planted sweet corn before ear formation in the test plot. *S. geminata* may have been relatively more common due to later planting of sweet corn because of lack of naturally occurring host resources. In the previous study, dropped mulberry fruit may have been available during sweet corn silking and ear fill (Dowd 2000).

A variety of trap designs have been used for sap beetles, but they typically have been constructed by researchers (Dowd et al. 1992, Williams et al. 1993, James et al. 1996). The current study indicated that a commercially available trap is suitable, because captures of the target sap beetle species, *C. lugubris,* were never significantly different for the two trap types. However, the fly trap may be more advantageous than the Tee trap when capturing *G. quadrisignatus* due to its greater efficiency, and thus sensitivity in detecting lower populations. One potential disadvantage of the "Fly-in Saucer" trap is that it can be more difficult to empty when contents become damp, due to the narrower mouth and tapered neck. The commercially available pheromone of *C. lugubris* is also suitable for field use in sweet corn, although it does not affect species in other genera (Williams et al. 1993). Thus, the one instance in 2003 where *G. quadrisignatus* was significantly more attracted to the USDA instead of the commercial pheromone source is not likely to be biologically relevant because only the coattractant is attractive to *G. quadrisignatus* (Williams et al. 1993).

As indicated previously, Bt sweet corn can be so effective in controlling *O. nubilalis* and *H. zea* that insecticide use can be greatly reduced or eliminated (Dively et al. 1998; Lynch et al. 1999a, b; Dowd 2000; Burkness et al. 2001; Musser and Shelton 2003). In addition, Bt sweet corn does not adversely affect beneficial insects and in some cases results in increased populations of *Orius* sp. relative to non-Bt sweet corn (Dowd 2000, Musser and Shelton 2003). These predator populations seem to have a significant effect on secondary aphid pests of sweet corn (Musser and Shelton 2003). However, as discussed previously, sap beetles can be a major pest of Bt sweet corn (Dively et al. 1998, Dowd 2000; current study), potentially requiring insecticide applications. The results of the current study indicate that traps and lures for effective monitoring of sap beetles, especially *C. lugubris,* in sweet corn are now commercially available. As described previously (Dowd 2000), trap-related economic thresholds will need to be specifically determined and may vary for different hybrids due to variations in husk coverage. As part of a management plan for mycotoxins in dent corn, two traps per field side in fields from ≈4 ha to 40 ha have given good relative estimates of sap beetle damage on ears at milk stage over the past few years (unpublished data). Because the European Union has recently approved the sale of Bt sweet corn (Elliott 2004), its market is likely to expand, making effective insect management of sap beetles a priority in expanding sweet corn acreage. Sap beetle monitoring also may be valuable in dent corn situations where mycotoxins are a problem, because sap beetles can be important vectors of the causal fungi (Dowd 1998).

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